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December 16, 1975

MEMO TO: J. R. Harbison
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SUBJECT: Research Report No. 439; "Evaluation of Paint-Stripe Beads;" KYP-73-48; HPR-PL-1(11), Part III B.

Painted lines and stripes on pavements are hardly perceptible at distance under headlights unless they are reflectorized. Although glass beads have been embedded in paint lines since World War II, reflectivity during rain and wetness has never been adequate. Larger, more sparsely distributed beads have been sought (to increase proudness and drainage in the valleys between beads); proper embedment and proper strength of bedding (paint) have been difficult to achieve. When epoxy resin paints came along, it was hoped that they would be strong enough to hold the larger beads. Drying time and poor adhesion to the pavement proved to be disadvantages. Some manufacturers of beads began to favor more uniformly sized beads and coatings on them to make them float on the wet paint (embed to their midpoint). Two years ago, Kentucky adopted quick-dry paints (90-second drying time) in order to avoid having to set out cones behind the striper while normal paints dried. We discovered belatedly that the new paints were drying so fast that the beads, dropped on almost immediately behind the spray gun, were not being embedded properly. Premature loss of beads has, therefore, resulted in severe losses in effectiveness of lines at night.

During the summer of 1974, which was the first year for quick-dry paints, the Division of Research began a series of field tests intended to produce comparative performance evaluations of the several types and gradations of beads then available. It seemed sufficient at that time to merely apply them according to the procedures established for quick-dry paints and to observe the lines from time to time. The belated discovery, there, that the beads had not been embedded properly almost nullified the original intent of the project. Indeed, there were some prominent differences in the performances of the beads; however, the ratings are believed to be biased by early losses of beads and poor embedment and retention.

The report submitted now relates the several circumstances which have compounded in a somewhat insidious way to create a more urgent and compelling problem. The report has been delayed while attempting to resolve the bead-bedding problem. Some urgency arises from the standpoint of performance tests conducted annually on paints (cross lines) -- that is, the basis for bidding and purchase of traffic paints in the following year. The lines for the 1976 season were applied in October; the same beads (Special Provision No. 62-C) were applied to all paints. It was discovered there, too, that the beads had not been bedded properly. Inasmuch as part of the rating and evaluation routine involves nighttime observations, the summary of performance ratings would depend somewhat on perchance retention of more or less beads on some lines than on others. For this reason, we proceeded to determine the necessary consistency of paints to assure embedment of beads. This involved progressive thinning with solvent and consequent extension of drying time. These findings are included in the report. We intend to make similar adjustments in the paints submitted for performance testing (leading to 1976 purchases) and to re-apply the lines at the same site as before. Both sets of lines will be observed and rated according to performance. It may be that thinning and drying time will have to be compromised in order to assure good retention of beads during next year's striping program. More specific recommendations in that respect will accompany those performance reports.

At the present time, I recommend that acquisitions of beads for next year's striping operations proceed on the basis of Special Provision No. 62-C (current) and the special recommendations at the end of the report.

Respectfully submitted,

Jas. H. Havens

Jas. H. Havens
Director of Research

JHH:gd
Attachment
cc's: Research Committee

Technical Report Documentation Page

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16. Abstract

The objectives of this phase of the overall "Roadway Delineation" study were to evaluate the luminosity and durability of several types of glass beads and one type of plastic bead used with paint stripes and to determine their effectiveness during rainy, nighttime conditions. Eleven types of beads were evaluated. They were applied at rates approximating 4, 5, and 6 pounds per gallon (479, 599, and 719 kg/m^3). Photometer and visual observations extended to about 9 months after application of test stripes.

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Glass beads	Gradation	
Plastic beads	Photometer	
Luminosity	Night visibility rating	
Durability	Application rate	

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Research Report
439

EVALUATION OF PAINT-STRIPE BEADS

KYP-73-48, HPR-PL-1(11), Part III B

by

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and

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Bureau of Highways
DEPARTMENT OF TRANSPORTATION
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INTRODUCTION

Driver visibility of a roadway is reduced by darkness and is further reduced by rain and water on pavements. A continuing effort has been made to develop effective and economical, reflective, pavement marking materials. Raised pavement markers have been evaluated previously *(1, 2)*. Several types were found to be effective as supplements to lane lines and as markings at lane drops and hazardous curves. Raised pavement markers are very effective in rainy nighttime. However, it is not economical and practical to use the markers in all locations under all circumstances. Their relatively high cost prohibits use on low-volume highways. Damage from snowplows have prevented their use in northern states. Some success with rubber snowplow blades has been achieved in areas where winter temperatures are relatively high and wet snow and slush are commonplace *(3)*.

Thermoplastic striping materials have been applied at thicknesses in the order of 1/8 inch (3.2 mm) in an attempt to delineate the roadway under poor visibility conditions. An evaluation of thermoplastic pavement striping materials applied to Kentucky highways revealed that the high initial costs could not be justified except in very high traffic volume locations *(4)*.

Another attempt to improve rainy, nighttime visibility involved grooving the pavement in a skip-line manner before painting in order to induce drainage around the beads *(5)*. The high cost of grooving was detering.

REVIEW OF LITERATURE

Generally, glass beads for reflectorizing markings on pavements have been applied at the rate of 6 pounds/gallon (719 kg/m^3) to fresh paint sprayed at 15 mils (0.38 mm) wet thickness. Beads for drop-on applications have typically ranged in diameter from the No. 20 sieve size to the No. 100 sieve size. A previous practice was to disperse glass beads in the paint. Beads dispersed in paint ranged from the No. 50 sieve size to the No. 200 sieve size and amounted to 3 1/2 to 4 pounds/gallon (419 to 479 kg/m^3). The major disadvantage of beads premixed with paint is the lack of immediate nighttime reflectivity because the beads are submerged in the paint and are not exposed until traffic wears the paint off the top of them. A common practice was to apply a top dressing of 2 or 2 1/2 pounds/gallon (240 or 300 kg/m^3) of glass beads by dropping them on the wet paint line. Advantages of premixed paint and beads were simpler application, less complicated equipment, and assured wetting of beads by the paint binder.

Recent trends have been toward "quick-drying paints" in an effort to accomplish paint-striping with a minimal disruption to traffic *(6)*. Standard traffic paints, which have drying times of 30 minutes to an hour, are generally being replaced by paints which will dry in 90 seconds or less. "Quick-drying" has been accomplished through the development of solvent-resin vehicles and by heating paint before spraying. With drying time reduced to a few seconds, the problem of obtaining proper embedment of drop-on beads has become rather critical. Some paints skin-dry before the beads can be applied. Application of heavier beads and use of a boot to guide the beads more directly onto the paint have been suggested as possible solutions *(6)*. Meanwhile, others have evaluated beads-on-paint systems from the standpoint of efficiency of beads in slower-drying paints.

A study by Penn State included a comparison of a moisture-proofed, wide-graded, low-index beads and the bisymmetric, flotation beads (40-80 sieve size) *(7)*. The regular beads were applied at the rate of 6 pounds/gallon (719 kg/m^3) with a 15-mil (0.38-mm) wet-film thickness of paint and the flotation beads at the rate of 4 pounds/gallon (479 kg/m^3) in a 10-mil (0.25-mm) thickness of paint. The flotation bead was similar in luminosity and durability to the regular beads but was definitely superior to the regular bead when both were applied at the same rates of 4 pounds/gallon (479 kg/m^3) and 10-mil (0.25-mm) thickness. Recommendations for improved performance in Pennsylvania included the use of uncoated glass as a substitute for so-called moisture-proof glass and the use of flotation-coated beads with a modified or wider gradation. It was noted that considerable savings could be realized by use of 4 pounds/gallon -- 10 mil (479 kg/m^3 -- 0.25 mm) applications *(7)*. That study also indicated that wider gradations would reduce production costs as well as improve performance.

In recent years, considerable effort has been devoted to research and usage of a glass bead originally manufactured by the 3M Company and known as the "bisymmetric bonding bead" *(8)*. These beads have the characteristic of uniform gradation (approximately 80 to 100 percent between the No. 40 and No. 80 sieve sizes) and the flotation ability. Beads treated for flotation must float in both xylol and heptane. Bisymmetric bonding means that the beads bond in the paint up to their equator. Flotation is attributed to surface tension and low wetting angle.

Evaluation of the floating-type beads by the Colorado Division of Highways led them to conclude that the small (90 percent between the No. 40 and No. 80 sieves) uniformly-graded beads are superior in both brightness and durability to the coarser glass beads *(9)*. Within a period of 3 years, it was estimated that the Colorado Division of Highways saved approximately $150,000 by applying the flotation bead at the rate of 4 pounds/gallon (479 kg/m^3) rather than the standard bead at 6 pounds/gallon (719 kg/m^3).

A 2-year study in New Jersey produced results showing that the uniformly-graded, floating beads provided the highest level of initial, night visibility and most consistent brightness compared to the standard, well-graded beads *(10)*. The required rates of application of the floating beads were found to be 4 pounds/gallon (479 kg/m^3) for bituminous pavements and 6 pounds/gallon (719 kg/m^3) for concrete pavements. At these rates, the floating beads provided approximately 50 percent greater brightness than standard beads on bituminous pavements and approximately 70 percent greater brightness on portland cement concrete pavements. The two other types of beads evaluated in the New Jersey study were uniformly-graded beads without the flotation characteristic and a well-graded, high index, floating bead which supposedly provided good nighttime visibility in rainy weather. Varied results were obtained from the uniformly-graded beads without the flotation characteristic. The visibility performance of these beads was extremely inconsistent, varying from less than the standard bead to approximately the same as the floating bead. The well-graded, high index, floating bead ("rain bead") performed effectively on portland cement concrete pavements but were not effective on bituminous pavements. Under rainy conditions, the "rain beads" initially showed a definite brightness advantage over other beads in the study. In subsequent evaluations, no advantage was detected.

A study by the Virginia Highway Research Council highlighted some problems normally encountered with regard to the control of the bead and paint application rates *(11)*. Included in the evaluation were the Virginia standard, well-graded bead, the uniformly-graded, floating bead, and the uniformly-graded, nonfloating bead. The results were not conclusive enough to indicate that any one of the three types was superior to the other under dry, night conditions. Under wet, night conditions, the floating bead appeared to be superior to the nonfloating bead.

Crumpton and McCaskill *(12)* in Kansas determined economical paint-and-bead application rates. One of the most significant observations from the field studies was that paint loss in Kansas was primarily due to chipping and not to wear. In addition, Kansas glass-bead specifications were changed and lower prices were realized. Other summaries are given in References 13, 14, and 15.

The purpose of this study was also to evaluate newer types of beads, to evaluate their efficiency and cost, to optimize application rates, and to revise Special Provision No. 62-C accordingly. Field testing began concurrently with the adoption of ultra-fast drying paints in Kentucky. The original intent and purpose were somewhat insidiously thwarted or nullified by the fact that the beads did not embed properly in the quick-dry paints used. It was discovered that the problem existed statewide and that the annual striping program was similarly imperiled. This report, therefore, not only relates the findings from the in-service tests but also addresses the more compelling problem.

PROCEDURE

Eight types of glass beads and one type of plastic bead were applied in the summer of 1974. Specifications and flotation characteristics for the nine types are presented in Table 1. Abbreviated identifications for the bead types are also given in Table 1. The paint was applied at approximately 15 mils (0.38 mm); the beads were applied at rates of 4, 5, and 6 pounds/gallon (479, 599, and 719 kg/m^3). Special Provision No. 62-C for Type I Glass Beads, as currently specified and used in Kentucky, is included as Appendix A.

The test sections were near Lexington on US 25 and US 421 (Richmond Road) between New Circle Road and KY 418 (1973 ADT = 17,740). This is a four-lane, divided highway and the white, skip lines were used as the test stripes. There were 39 individual test sections, approximately twenty 15-foot (4.6-m) lane lines per section. Table 2 lists the number of test sections of each bead type and application rates.

The paint and beads were applied with a Prismo Universal Mini-Niteliner Test Paint Striper. Heated, fast-drying paint used throughout the state in 1974 was used to simulate the actual field application of paint and beads.

TABLE 1. GRADATION SPECIFICATIONS OF VARIOUS BEAD TYPES (TOTAL PERCENT PASSING)

BEAD TYPE	ABBREVIATION FOR BEAD TYPE	SIEVE SIZES – US STANDARD												
		14	16	18	30	40	45	50	60	70	80	100	130	200
Cataphote Regular (Present Kentucky Specification)	CAT (REG)		100		45-95			15-35				0-5		
Cataphote Floating (Uniformly Graded)	CAT(-40+80)				100	90-100					0-15			
Cataphote Floating (Well Graded)	CAT (KY SPEC)		100		45-95			15-35				0-5		
Flex-O-Lite (Floating)	FOL				98-100			20-50			0-10			
Flex-O-Lite Safe-Ray 765	FOL 765		100	98-100	60-90			15-50				0-10		[illegible]
Flex-O-Lite TT-B (Type III(A))	FOL TT-B	100		80-90	15-70	0-5								
3M Floating (Old Gradation)	3M (OLD)				100	90-100					0-10			
3M Floating (New Gradation)	3M (NEW)				100			90-100			0-10			
Koppers (Polyester Beads)	PLASTIC				100	96	81	51	31	21	12	7	5	

TABLE 2. NUMBER AND APPLICATION RATES OF TEST SECTIONS OF EACH BEAD TYPE

BEAD TYPE	NUMBER OF TEST SECTIONS	APPLICATION RATES POUNDS/GALLON (kg/m^3)
CAT (REG)	5	7.5 (898), 6.4 (767), 5.3 (635) 4.2 (503), 2.5 (300)
CAT (-40+80)	3	5.8 (695), 3.4 (407), 2.5 (300)
CAT (KY SPEC)	4	5.9 (707), 4.8 (575), 3.6 (431), 3.5 (419)
FOL	4	4.8 (575), 4.0 (479), 3.0 (395), 2.9 (347)
FOL 765	4	7.8 (934), 6.4 (767), 4.8 (575), 3.3 (359)
FOL TT-B	3	8.0 (958), 6.4 (767), 4.5 (539)
3M (OLD)	4	6.7 (803), 5.6 (671), 2.5 (300), 1.5 (180)
3M (NEW)	7	7.5 (898), 7.2 (862), 6.6 (791), 6.0 (719), 5.5 (659), 4.0 (479), 2.2 (264)
PLASTIC[a]	5	8.4 (1006), 6.1 (731), 4.8 (575), 4.3 (515), 3.2 (383)

[a]Application rates shown have been converted to the equivalent rate for glass beads using a density ratio of 2.27.

To further investigate the rainy, nighttime visibility problem, two additional types of beads were obtained after completing the testing of the original nine types. One was a 1.65 refractive index bead between the No. 10 and No. 20 sieve sizes and the other was a nonfloating, 1.52 refractive index bead between the No. 20 and No. 30 sieve sizes. Both were obtained from Cataphote. Gradation specifications for these two bead types are presented in Table 3. The larger diameter beads and seven other types previously tested were applied at approximately 5 pounds/gallon (599 kg/m^3) in 6-foot sections on the Division of Research parking area. Wet-film thicknesses of paint ranging from 15 to 25 mils (0.38 to 0.64 mm) were used, depending on the sizes of the beads. The two new beads along with some of the beads previously evaluated were also applied, in the summer of 1975, to the same section of highway used before. Since these types had not been subjected to traffic for a sufficient time to evaluate their durability, only their early performance is being reported.

Nighttime reflectance or luminosity was monitored with a specially constructed photometer, similar to a device developed by Colorado *(9)*. Major components of the photometer are a sealed-beam spotlight, lens and photocell assemble, and a transistor amplifier. Output from the photometer was recorded on a strip chart. The spotlight and detector were mounted on a vehicle as shown in Figure 1. The photometer was aimed at a point on the pavement 10 feet (3 meters) in front of the vehicle. Measurements were taken at night by driving the vehicle slowly along the roadway with the spotlight centered over the lane-line stripes. Chart readings were later converted to equivalent luminance (footlamberts (candela/square meter)) through the calibration curves shown in Figure 2. The calibration curves were derived in the laboratory by relating the photometer output to readings from a General Electric light meter (Type SL 480A).

The final set of data was taken with a revised photometer. The photometer was altered because it had reached its maximum output for some of the bead types during previous testing. The magnitude of the last set of luminosity readings are not directly comparable with the preceding data. However, the ranking of the bead types was similar. It is not possible, therefore, to relate the differences in luminosity among various bead types on the same scale throughout the survey period.

Data were collected over a 261-day period between June 1974 and March 1975. Five sets of photometer data were taken, and three visual evaluations were made. Visual observations were made according to ASTM D 713-69, which is the standard method of "Conducting Road Service Tests on Traffic Paint".

TABLE 3. GRADATION SPECIFICATIONS OF VARIOUS BEAD TYPES (TOTAL PERCENT PASSING)

BEAD TYPE	SIEVE SIZES - US STANDARD														
	10	14	16	18	20	30	40	45	50	60	70	80	100	120	200
Cataphote Regular (Present Kentucky Specification)			100			45-95			15-35				0-5		
3M Floating (New Gradation)						100			90-100			0-10			
Cataphote Hi-Glo (Standard)			100	98-100		60-90			15-50				0-10		0-5
Cataphote Floating (Uniformly Graded)						100	90-100					0-15			
Cataphote Floating (Well Graded)			100			45-95			15-35				0-5		
Koppers (Polyester Beads)						100	96	81	51	31	21	12	7	5	
Cataphote Non-Floating (Large Diameter)					95	5									
Cataphote TT-B (Type III(A))		100		80-90		15-70	0-5								
Cataphote Hi-Glo (Large Diameter)	75				25	0									

Figure 1. Photocell Assembly and Spotlight Mounted on Vehicle.

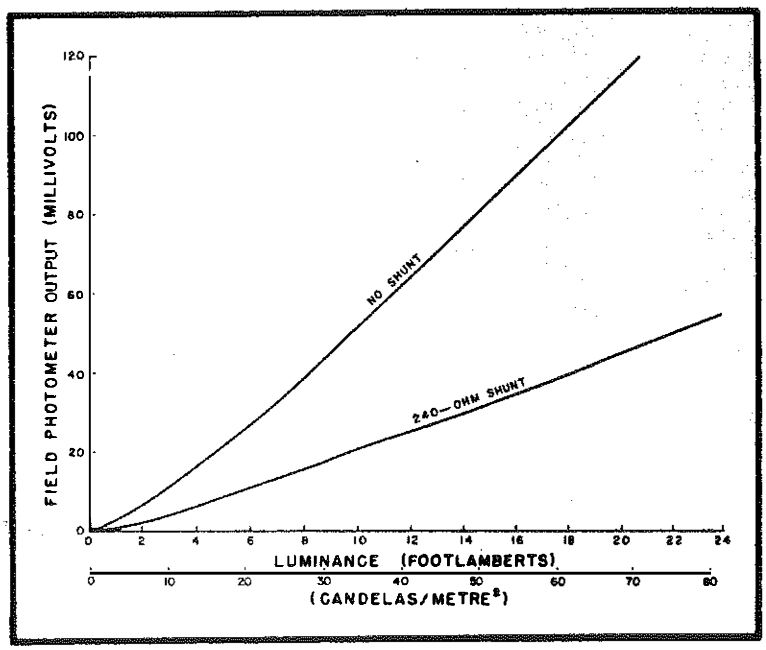


Figure 2. Calibration Curves for Field Photometer.

RESULTS

One method of analysis consisted of comparing luminosity readings of various bead types on test sections where the application rates were approximately equal. An application rate of 5 pounds/gallon (599 kg/m^3) was chosen because all the bead types had a test section near that rate of application and it was close to the average of the rates tested. The results are given in Table 4. The first three sets of data had several sections which exceeded the maximum photometer output. Originally, all the sections exceeded the maximum. However, the nonfloating glass beads lost luminosity faster than any other type. There was a large variation in the readings from the various brands of floating beads.

One set of data was taken during wet-pavement conditions immediately after a rainfall. The luminosity of the paint stripes was very low. The data was taken with the unaltered photometer. The results (Table 5) are very similar to the previous findings with the high refractive index and certain brands of the floating glass beads giving the best results. None of the beads showed good wet-pavement reflection.

Nighttime, Visual Ratings

Visual evaluation of the test sections during dry conditions were conducted immediately after installation of the stripes and 8 months later. The data were analyzed by the same method used for the photometer data. The findings were very similar (Figure 3). There was a variation in the results from the various brands of floating beads. The floating and 1.65 refractive glass beads had the highest rating. The nonfloating glass beads and plastic beads had the lowest rating.

One set of data was taken during wet-pavement conditions with the same type of analyses used as with dry data (Table 6). There was a variation in the results, but the high refractive index glass bead and certain brands of the floating beads had the highest rating. None of the beads had high ratings during rain.

TABLE 4. COMPARISON OF LUMINOSITY OF VARIOUS BEAD TYPES (ALL APPLICATION RATES APPROXIMATELY 5 POUNDS/GALLON (599 kg/m^3)) – DRY PAVEMENT

BEAD TYPE	APPLICATION RATE (POUNDS/GALLON (kg/m^3))	LUMINOSITY – FOOTLAMBERTS (CANDELAS/METER^2) AFTER INDICATED DAYS IN SERVICE			
		0[a]	87[a]	247[a]	261[b]
3M (NEW)	5.5 (659)	3.2 (11.0)	3.2 (11.0)	3.2 (11.0)	1.00 (3.4)
FOL 765	4.8 (575)	3.2 (11.0)	3.2 (11.0)	3.2 (11.0)	.92 (3.2)
FOL TT-B	4.5 (539)	3.2 (11.0)	3.2 (11.0)	3.2 (11.0)	.69 (2.4)
3M (OLD)	5.6 (671)	3.2 (11.0)	3.2 (11.0)	3.2 (11.0)	.67 (2.3)
FOL	4.8 (575)	3.2 (11.0)	3.2 (11.0)	3.2 (11.0)	.60 (2.1)
PLASTIC	4.3 (515)	3.2 (11.0)	3.2 (11.0)	1.8 (6.2)	.60 (2.1)
CAT (KY SPEC)	4.8 (575)	3.2 (11.0)	2.8 (9.6)	2.2 (7.5)	.58 (2.0)
CAT (-40+80)	5.8 (695)	3.2 (11.0)	2.7 (9.2)	2.0 (6.8)	.43 (1.5)
CAT REG	5.3 (635)	3.2 (11.0)	0.9 (3.1)	1.2 (4.1)	.20 (.69)

[a]The maximum reading possible on the photometer was 3.2 footlamberts (11.0 candelas/meter^2).

[b]The photometer was revised

TABLE 5. RANKING OF LUMINOSITY FOR VARIOUS BEAD TYPES ON WET PAVEMENT (APPLICATION RATES APPROXIMATELY 5 POUNDS/GALLON (599 kg/m^3)) (AFTER 153 DAYS IN SERVICE)

BEAD TYPE	APPLICATION RATE (POUNDS/GALLON (kg/m^3))	LUMINOSITY (FOOTLAMBERT (cd/m^2))
FOL TT-B	4.5 (539)	.73 (2.5)
FOL 765	4.8 (575)	.45 (1.5)
3M (NEW)	5.5 (659)	.41 (1.4)
3M (OLD)	5.6 (671)	.28 (.96)
PLASTIC	4.3 (515)	.26 (.89)
CAT (KY SPEC)	4.8 (575)	.22 (.75)
CAT (REG)	5.3 (635)	.21 (.72)
CAT (-40+80)	5.8 (695)	.19 (.65)
FOL	4.8 (575)	.15 (.51)

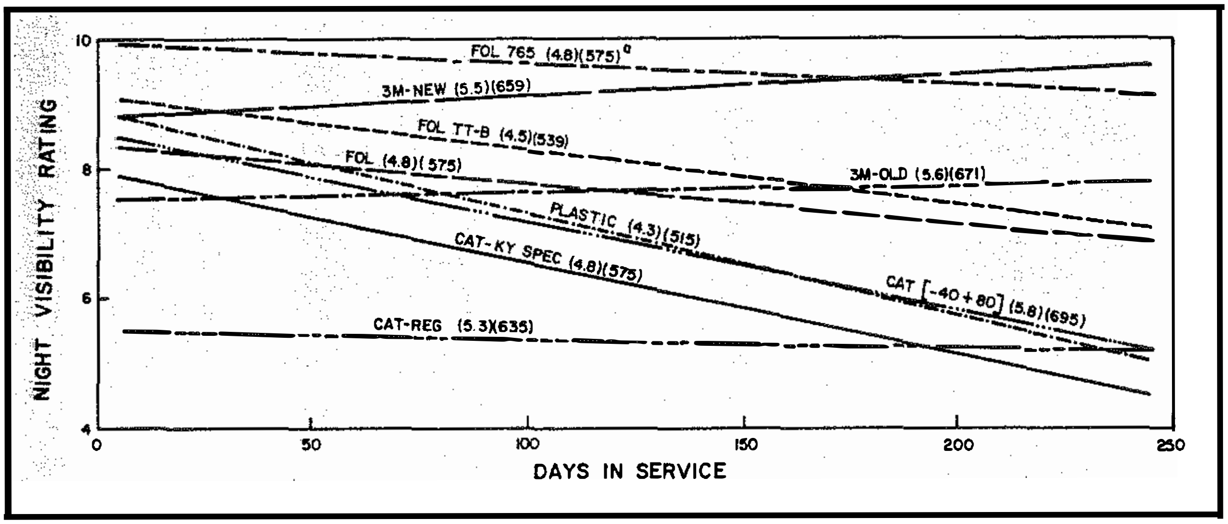


Figure 3. Comparison of Night Visibility Ratings for Various Bead Types (All Application Rates Approximately 5 Pounds of Beads (599 kg/m^3) per Gallon of Paint) (Dry Pavement).

TABLE 6. RANKING OF NIGHTTIME VISIBILITY RATINGS FOR VARIOUS BEAD TYPES ON WET PAVEMENT (APPLICATION RATES APPROXIMATELY 5 POUNDS/GALLON (599 kg/m^3)) (AFTER 153 DAYS IN SERVICE)

BEAD TYPE	APPLICATION RATE (POUNDS/GALLON (kg/m^3))	WET, NIGHTTIME VISIBILITY RATING
FOL 765	4.8 (575)	5.7
FOL TT-B	4.5 (539)	5.0
3M (NEW)	5.5 (659)	3.7
CAT (KY SPEC)	4.8 (575)	3.0
CAT REG	5.3 (635)	3.0
3M (OLD)	5.6 (671)	2.7
PLASTIC	4.3 (515)	2.7
FOL	4.8 (575)	1.7
CAT (-40+80)	5.8 (695)	1.3

Appearance, Durability, and Weighted Ratings

When the visual observations were made, the daylight appearance and durability of the paint stripe were rated as well as night visibility. These ratings for application rates of approximately 5 pounds/gallon (599 kg/m^3) after 247 days in service are given in Table 7. The beads which had the highest night visibility ratings (dry) also had the highest appearance and durability ratings; the difference between the best and worst in daylight were not as great as the differences in night visibility ratings.

Comparison of Photometer Data and Nighttime Visibility Ratings

A comparison was made between the photometer data and the night visibility ratings. A computer-fit curve (Figure 4) showed a high correlation between the two methods. In addition to evaluating the various bead types, a critical question was the optimum application rate to be used. Computer plots of application rates (pounds of beads per gallon of paint) for each of the major bead types studied versus luminosity and night visibility ratings were drawn (Figures 5 and 6). Data were taken after several months in service. Data from all the test sections were used to obtain these plots. The assumption was made that the luminosity and night visibility ratings would be zero on paint stripes without beads. Both linear and quadratic fits were established. The squared correlation coefficients for the quadratic fits were higher than for the linear fits. The quadratic fits were selected because they gave the more realistic curves -- that is, beyond a certain application rate, additional beads would not have increased luminosity. Both figures tend to indicate the high refractive index (1.65 and 1.92) and floating glass beads to be superior to the nonfloating glass beads and plastic beads. Compared to the standard, nonfloating beads presently used in Kentucky at the rate of 6 pounds/gallon (719 kg/m^3), the application rate of the 1.65 refractive-index and the 3M floating beads could be reduced to about 2 1/2 and 3 pounds per gallon (300 and 359 kg/m^3), respectively, without sacrificing luminosity. Unfortunately, none of these results is conclusive inasmuch as the embedment of beads in the paint was not adequate at the outset and inasmuch as losses of beads may have occurred before the first evaluation was made.

TABLE 7. VISUAL OBSERVATION RATINGS FOR VARIOUS BEAD TYPES ON DRY PAVEMENT (APPLICATION RATES APPROXIMATELY 5 POUNDS/GALLON (599 kg/m^3)) (247 DAYS IN SERVICE)

BEAD TYPE	APPLICATION RATE (POUNDS/GALLON (kg/m^3))	RATINGS			
		APPEARANCE	DURABILITY	NIGHT VISIBILITY	WEIGHTED
3M (NEW)	5.5 (659)	8.4	8.7	9.6	9.0
FOL 765	4.8 (575)	8.2	8.6	9.2	8.7
FOL TT-B	4.5 (539)	8.0	8.2	7.1	7.7
FOL	4.8 (575)	8.0	8.5	6.9	7.7
3M (OLD)	5.6 (671)	6.2	6.8	7.8	7.0
CAT (KY SPEC)	4.8 (575)	7.8	7.1	4.8	6.4
CAT REG	5.3 (635)	6.0	7.0	5.2	6.0
CAT (-40+80)	5.8 (695)	6.4	6.4	5.2	5.9
PLASTIC	4.3 (515)	6.0	5.9	3.5	5.0

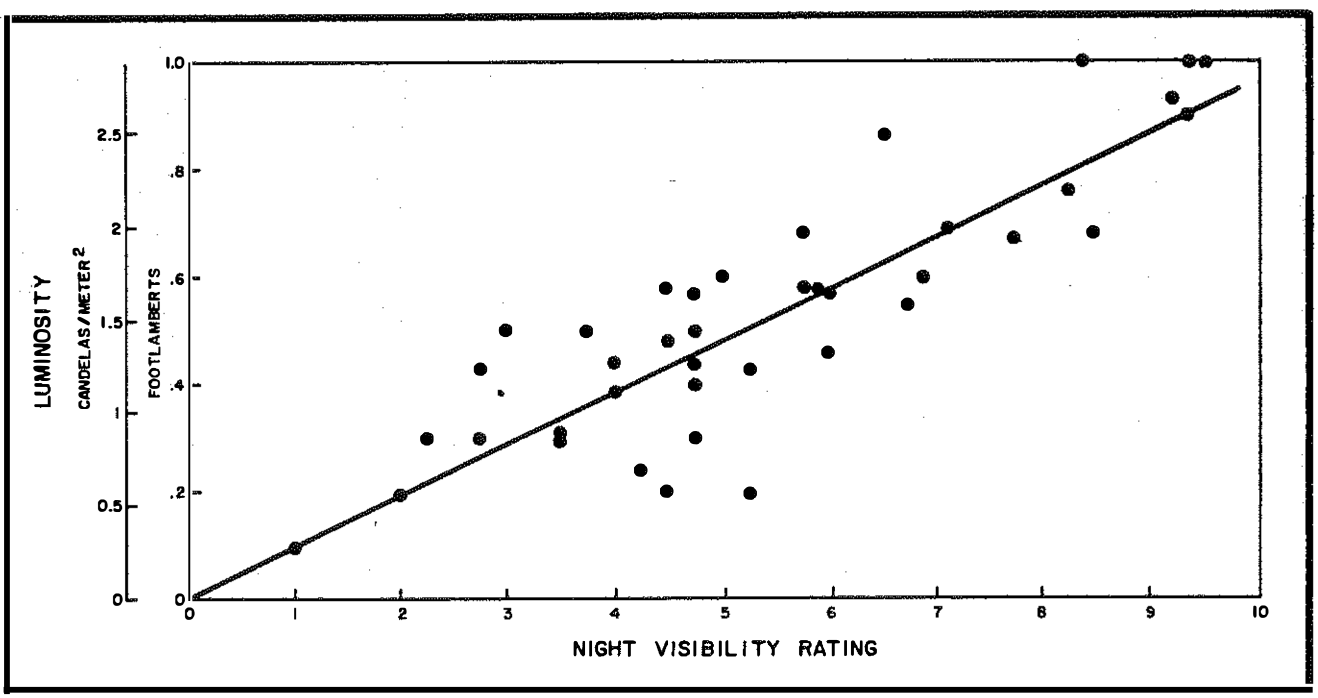
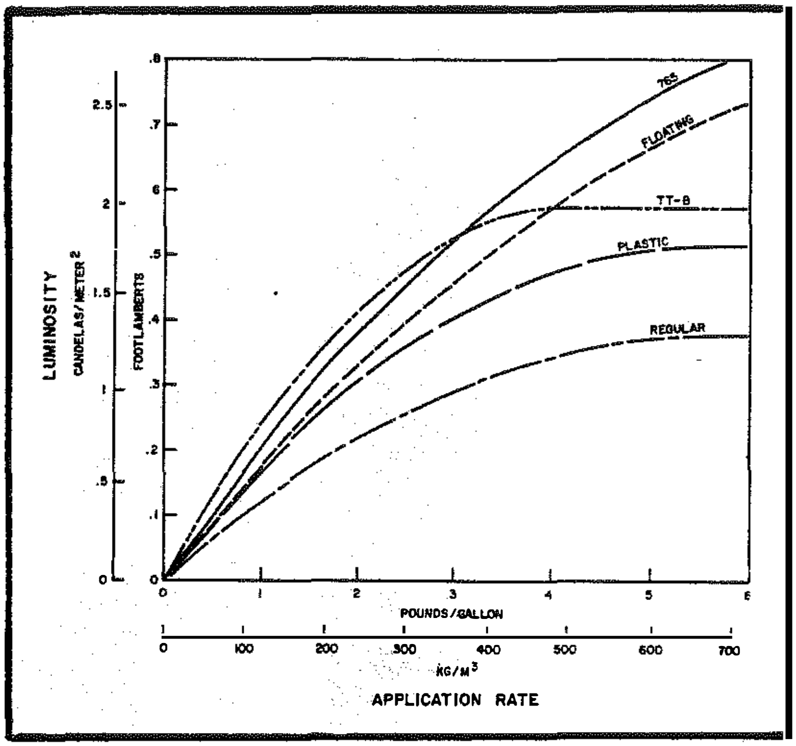


Figure 4. Comparison of Luminosity versus Night Visibility Rating.

Figure 5. Luminosity versus Application Rate for Various Bead Types (after 261 Days in Service).



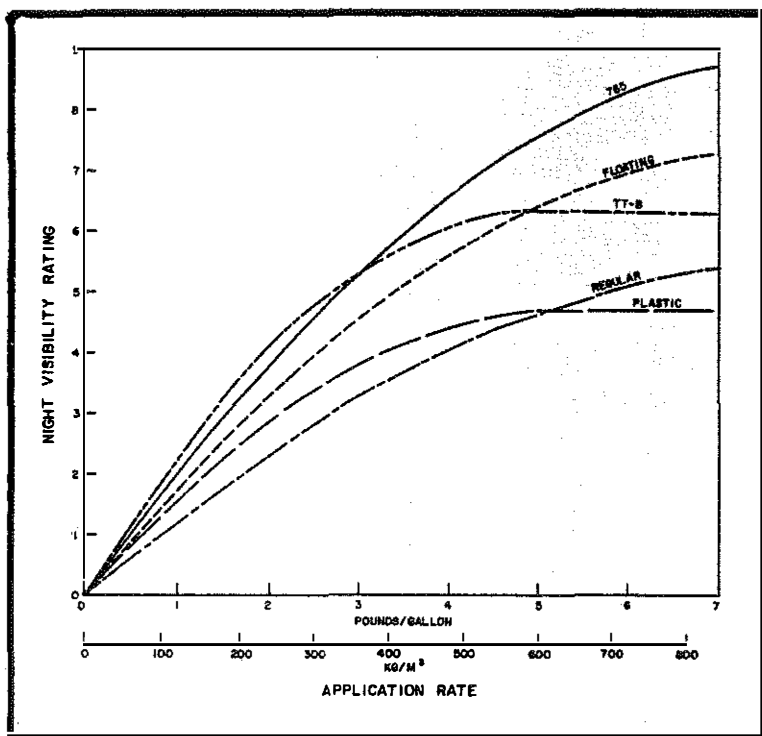


Figure 6. Night Visibility Rating versus Application Rate for Various Bead Types (after 248 Days in Service).

Embedment and Retention of Beads

Whereas beads should be socketed or embedded at least to their mid-height, premature losses of beads from lines are generally attributable to poor embedment in the paint at the time of application. Wind, temperature, and viscosity, depth, and drying time of paint are affecting factors. Indeed, there were premature losses of beads in practically all of the performance trials. A series of photomicrographs (Figures 7 through 19) are illustrative. Some show comparatively the initial embedment and corresponding losses after time in service. In some instances, the photos were made from specimens of lines, preserved on plates, applied in the summer of 1973 but not evaluated; the final-condition photos were made in November 1975 of lines applied in the summer of 1974 and evaluated through 261 days. Poor embedment, undoubtedly, affected reflectance from the very beginning. Ratings of performance were, therefore, invalidated; and a more compelling concern evolved -- that is, the prerequisite condition of assuring proper embedment of beads in ultra-quick-drying paints. Figure 20 *(16)* shows ideal embedment.

A second series of photos, Figures 21 through 24, show larger-than-normal beads on lines applied in 1975 in an effort to evaluate their performance (reflectivity) during rain. There, too, the embedment was not adequate; and evidently, there were early losses of beads.

Generally, the paint did not wet the beads; and there was a downward dipping of the paint surface toward the contact. Some socketing occurred because of weight and inertia of the beads. Later, in re-trials, it was found impossible to aim the beads and paint dispensers to obtain the desired embedment. Recourse was then made to thinning the paint. Figures 25 through 27 show trial applications with paint diluted 5, 10, and 15 percent, respectively; only the latter produced acceptable results.

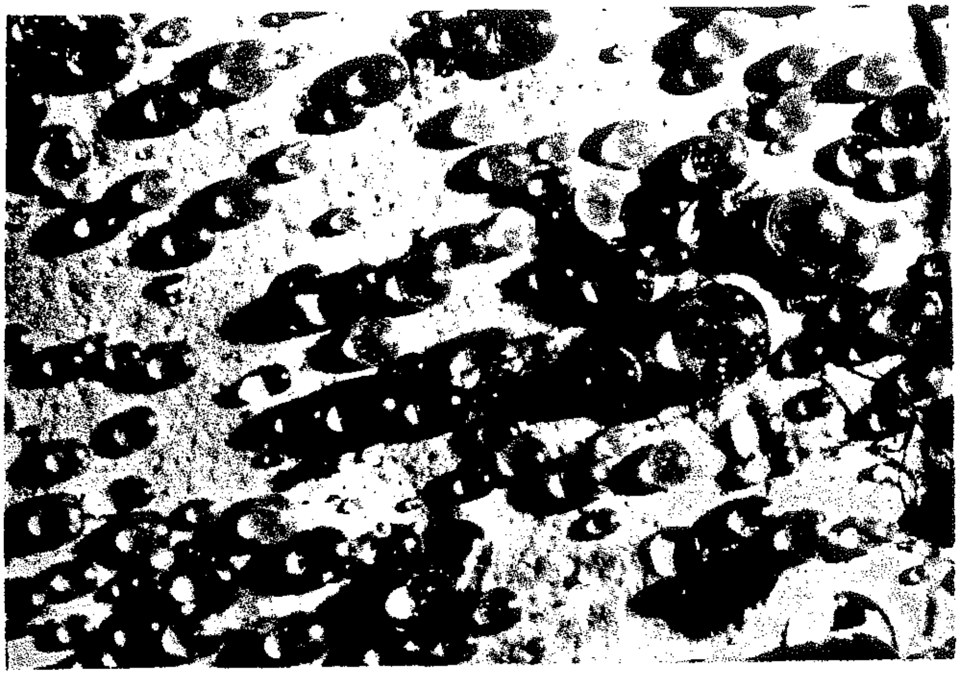
Figure 28 shows paint samples taken in the Lexington District in November 1975. Figure 29 shows embedment achieved later by the painting crew in the Louisville District after adjustments upon instructions by the Traffic Division were made. It is imperative, of course, that this condition be achieved statewide to assure maximum benefit and service to the public.

Rates of Application and Sizes of Beads

The length of 4-inch (100-mm) wide stripe which can be placed at a thickness of 15 mils (0.38 mm) with 1 gallon (0.0038 m^3) of paint is 321 feet (98 m) (gallon per mile/1.1 = thickness in mils). The weight of beads (in a neat square arrangement) necessary to completely cover the paint is 120 x pounds of glass per cubic inch x diameter of beads/thickness of paint; normal-weight glass weighs approximately 0.094 pounds/cubic inch (2.6 Mg/m^3); lbs (beads)/gal (paint) = 120 x 0.094 x 1.1 x diameter (beads) in mils/thickness (paint) in mils. The volume of beads necessary to cover 321 feet (98 m) of 4-inch (100-mm) stripe was found to be 785 cubic inches (0.013 m^3). This considers the fact that a sphere occupies 52 percent of the volume of a box with sides equal to the diameter of the sphere. Since the weight of glass is equal to 0.094 pounds per cubic inch (2.6 Mg/m^3), the weight of beads 9.8 mils (0.25 mm) in diameter (No. 60 sieve) necessary to completely cover paint applied at 15 mils (0.38 mm) is 7.4 pounds per gallon (887 kg/m^3). Beads 15 mils (0.38 mm) in diameter on paint applied at 15 mils (0.38 mm) thickness would amount to 12.4 pounds per gallon (1,485 kg/m^3). Floating beads require paint depths at least equal to half their diameter.

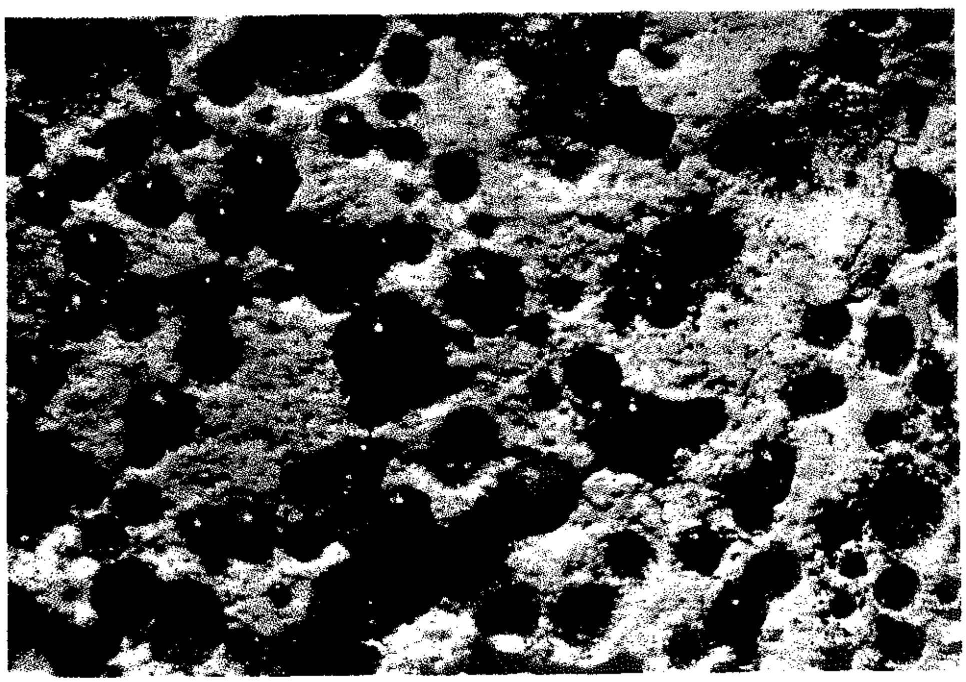
An optimum situation may be found for nonfloating beads when they are embedded to one-half their diameter and are resting on the pavement. Given that the paint is applied at a thickness of 15 mils (0.38 mm), the size of bead is found by equating half the diameter of the bead to the thickness of the paint stripe and considering the fact that the beads will increase the depth of paint. This yields a diameter of 62.5 mils (1.59 mm). This size bead is approximately equal to the No. 12 sieve. Conversely, the paint application rate necessary to embed a certain size bead to one-half of its diameter with the assumption that the bead rests on the substrate can be calculated. The density or dispersion of the beads can also be varied. A paint thickness of only 4.3 mils (0.11 mm) would be necessary to embed a bead with a diameter of 9.8 mils (size of No. 60 sieve) to one-half its diameter assuming a three-diameter gap between adjacent beads. Assuming a spacing of one diameter between adjacent beads and a bead diameter of 9.8 mils (0.25 mm), the necessary paint thickness would be 3.6 mils (0.09 mm).

The spacing (density) of the glass beads is directly related to the size bead necessary to be embedded to one-half of its diameter when a paint thickness of 15 mils (0.38 mm) is applied (bead resting on pavement). As calculated earlier, the diameter of bead required when the beads are arranged with edges touching was 62.5 mils (1.59 mm). When there is a one-bead-diameter gap between beads, the required bead diameter becomes 40.5 mils (1.03 mm). The required diameter is 34 mils (0.86 mm) when there is a three-diameter gap between adjacent beads.



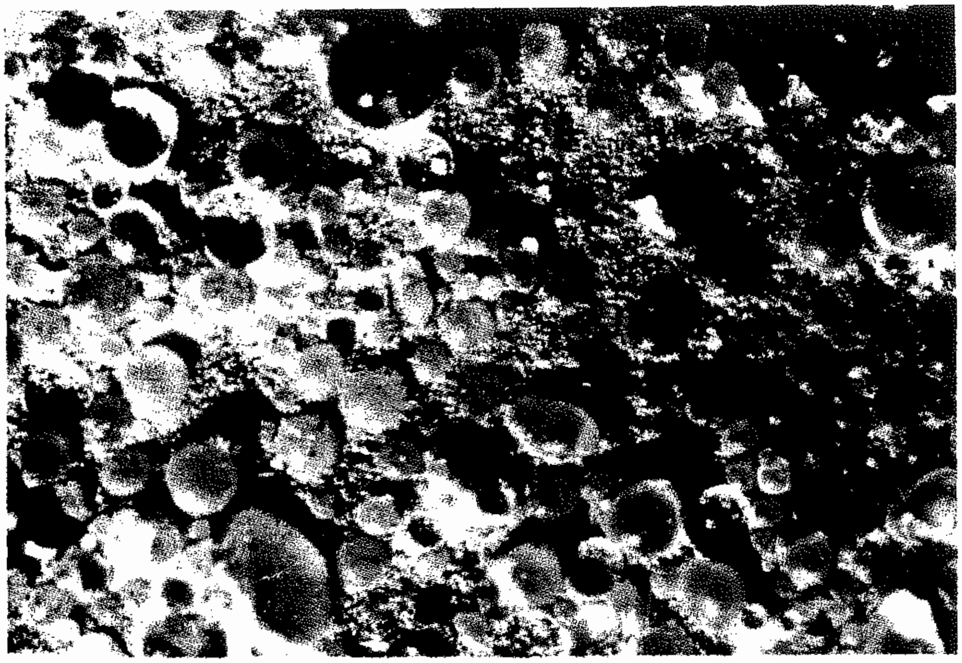
17 x magnification

Figure 7. Cataphote Regular Beads (Present Kentucky Specifications) Applied at 5.3 Pounds/Gallon (635 kg/m^3); Specimens of Line Preserved on Pick-up Panel; Summer 1974.



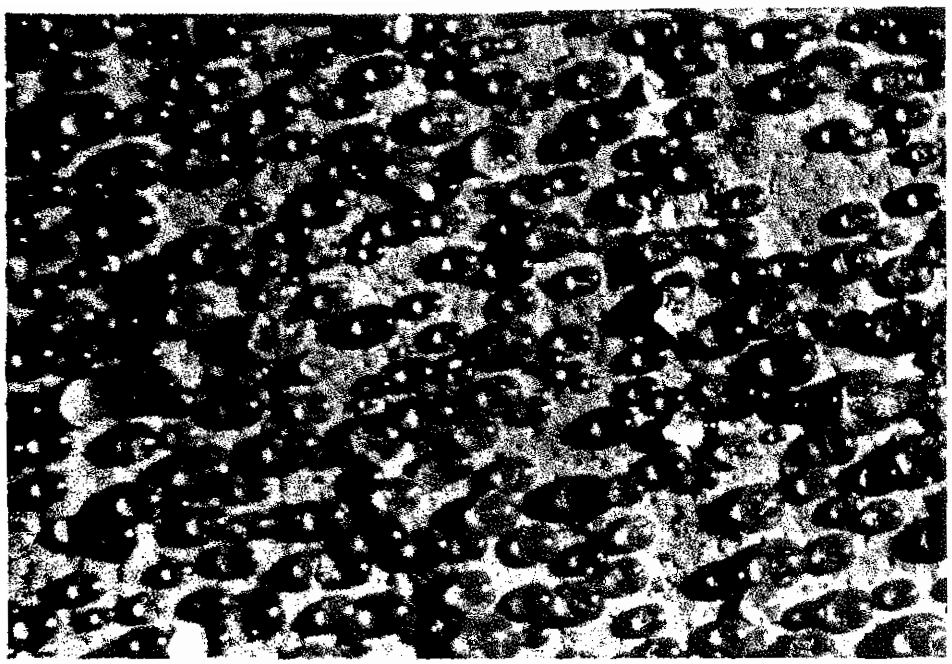
17 x magnification

Figure 8. Cataphote Regular Beads (Present Kentucky Specifications) Applied at 6.0 Pounds/Gallon (719 kg/m^3); Applied in Summer of 1975, US 25 (Test Site); Photo Made in November 1975.



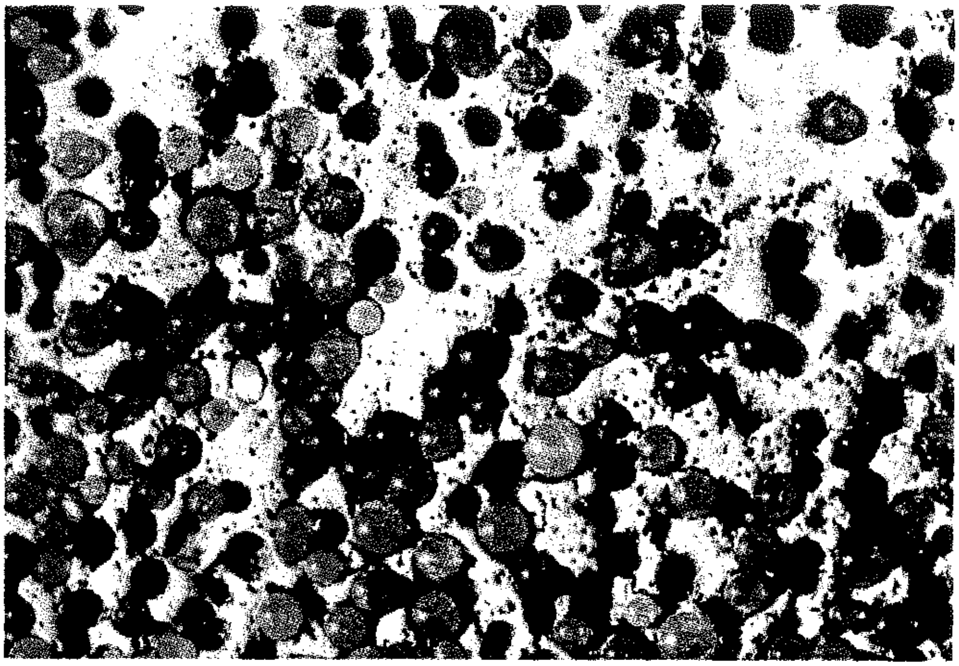
17 x magnification

Figure 9. Cataphote Regular Beads (Present Kentucky Specifications); Edgeline, Asphalt Pavement; Applied by District 7; 1975.



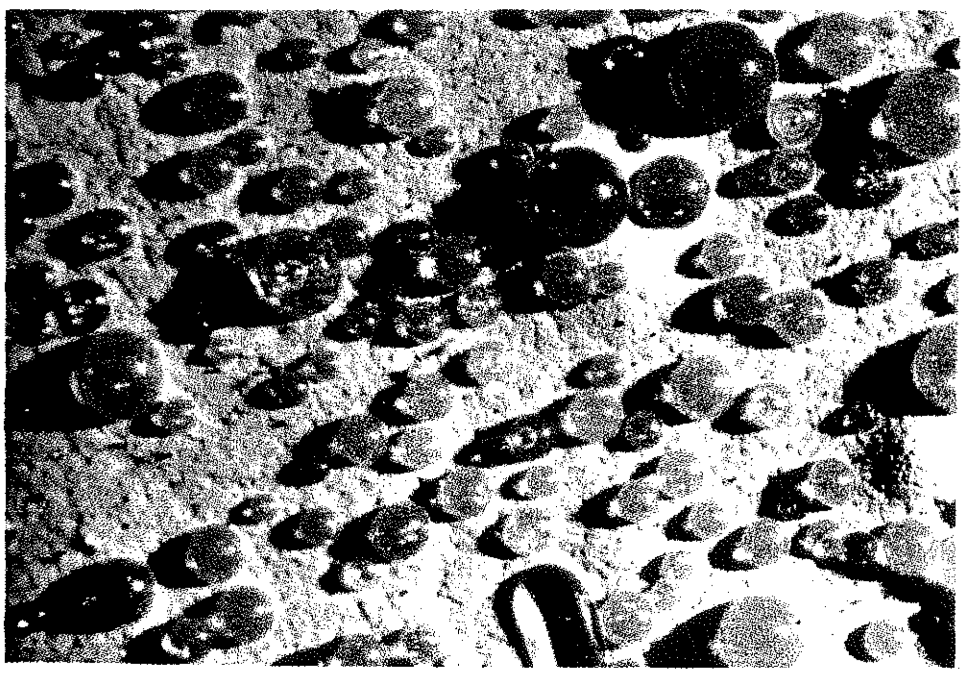
17 x magnification

Figure 10. 3M Floating Beads Applied at 4.0 Pounds/Gallon (479 kg/m^3); Specimen of Line Preserved on Pick-up Panel; Summer 1974.



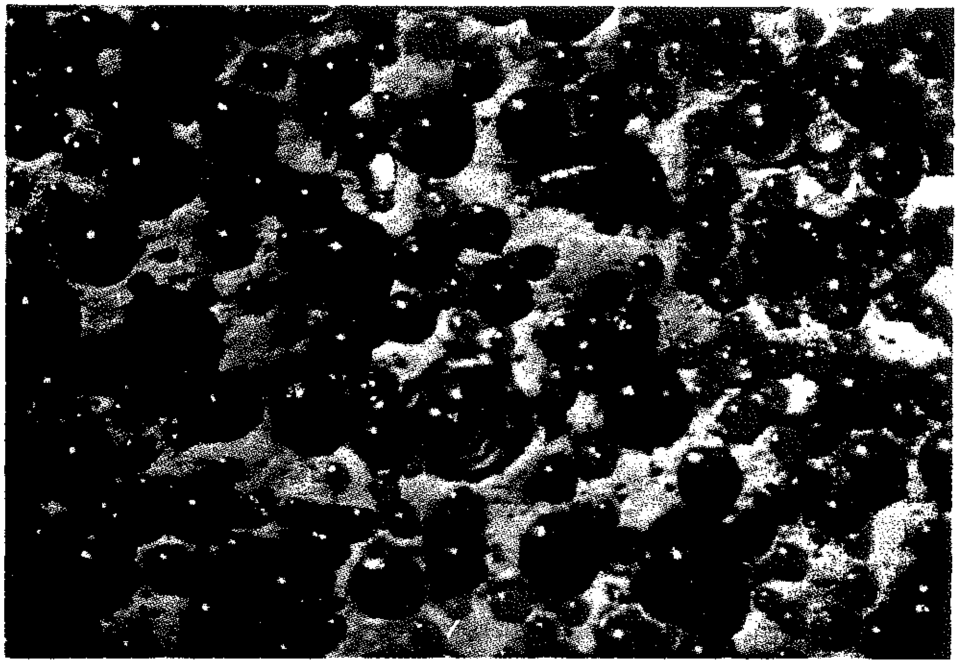
17 x magnification

Figure 11. 3M Floating Beads Applied at 4.0 Pounds/Gallon (479 kg/m^3); Applied in Summer of 1975, US 25 (Test Site); Photo Made in November 1975.



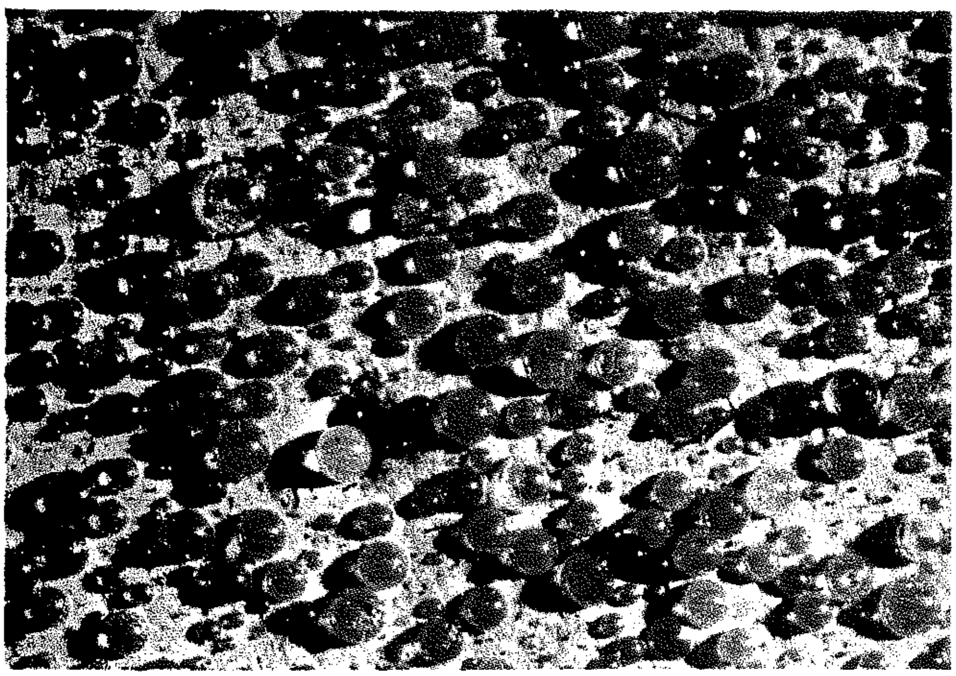
17 x magnification

Figure 12. Flex-O-Lite 765 (1.65 Refractive Index) Beads Applied at 4.8 Pounds/Gallon (575 kg/m^3); Specimen of Line Preserved on Pick-up Panel; Summer 1974.



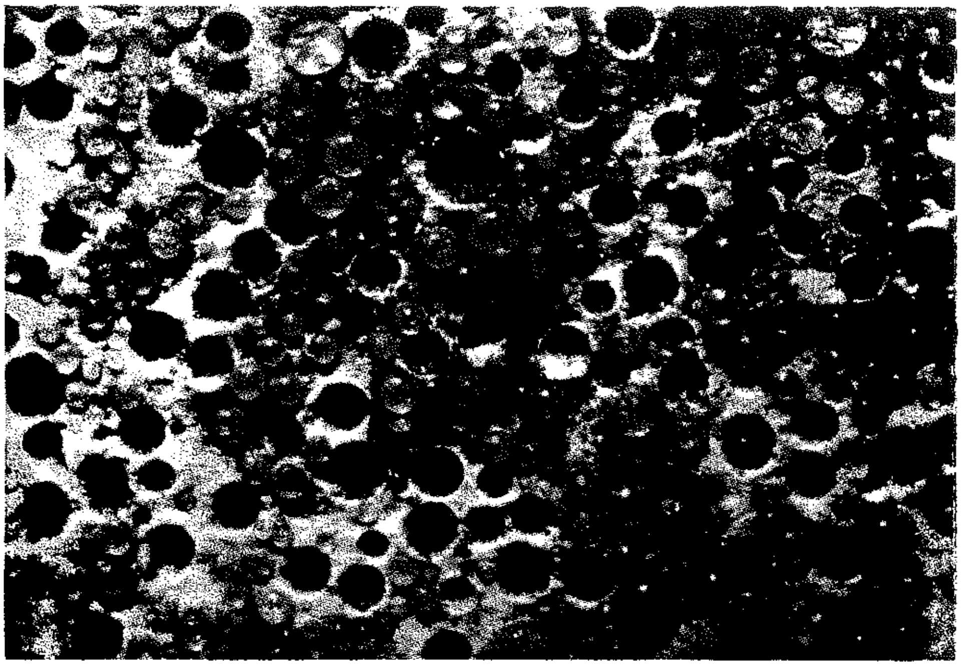
17 x magnification

Figure 13. Flex-O-Lite 765 (1.65 Refractive Index) Beads Applied at 4.0 Pounds/Gallon (479 kg/m^3); Applied in Summer of 1975, US 25 (Test Site); Photo Made in November 1975.



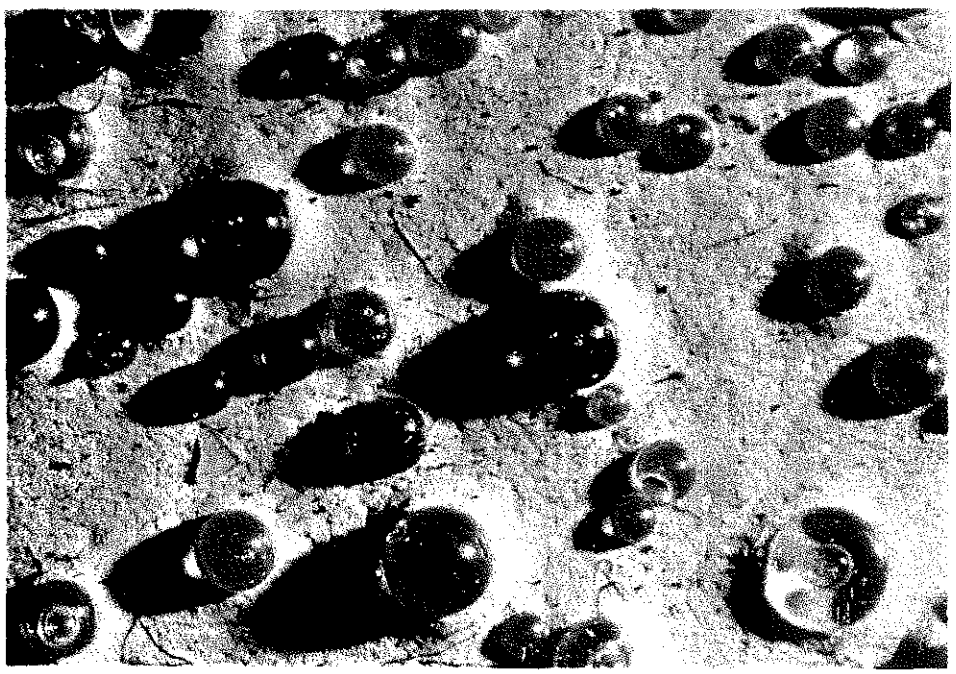
17 x magnification

Figure 14. Koppers Plastic Beads Applied at an Equivalent 4.3 Pounds/Gallon (515 kg/m^3); Specimen of Line Preserved on Pick-Up Panel; Summer 1974.



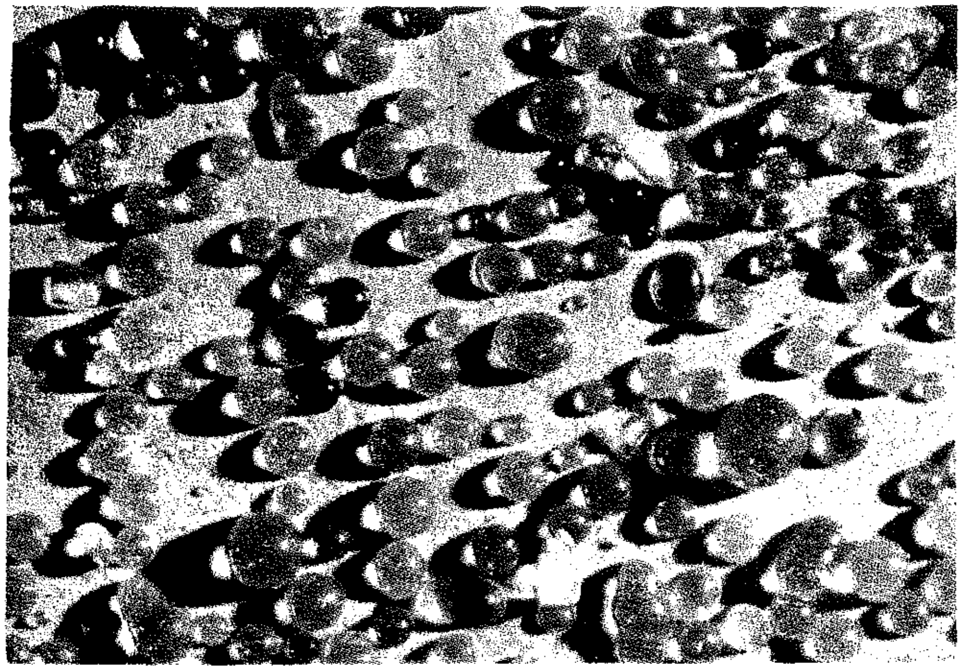
17 x magnification

Figure 15. Koppers Plastic Beads Applied at an Equivalent 5.0 Pounds/Gallon (599 kg/m^3); Applied in Summer of 1975, US 25 (Test Site); Photo Made in November 1975.



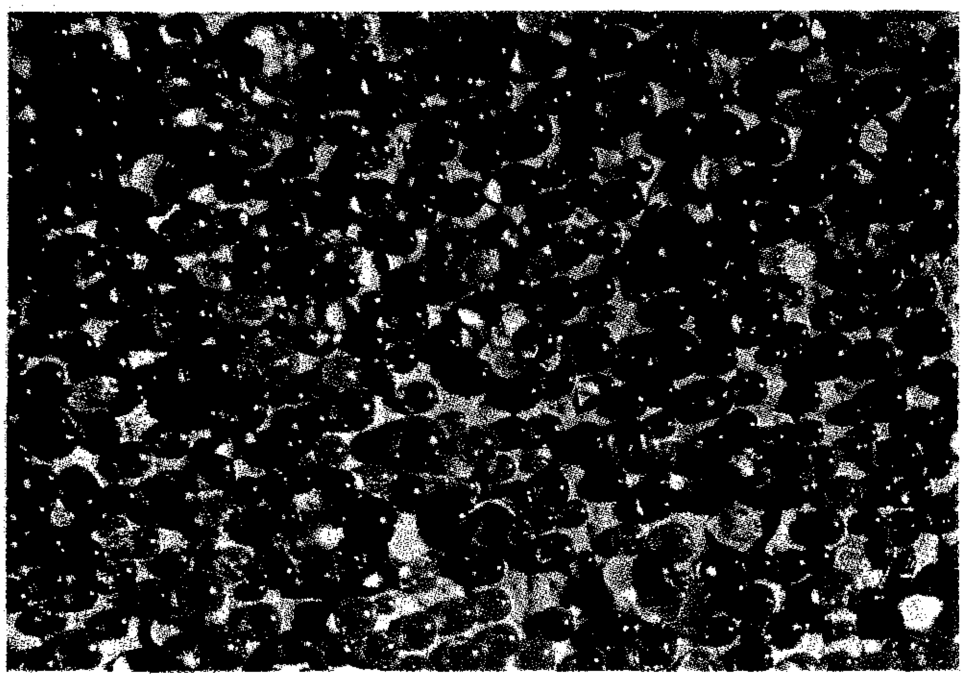
17 x magnification

Figure 16. Flex-O-Lite TT-B Beads (1.92 Refractive Index) Applied at 4.5 Pounds/Gallon (539 kg/m^3); Specimen of Line Preserved on Pick-up Panel; Summer 1974.



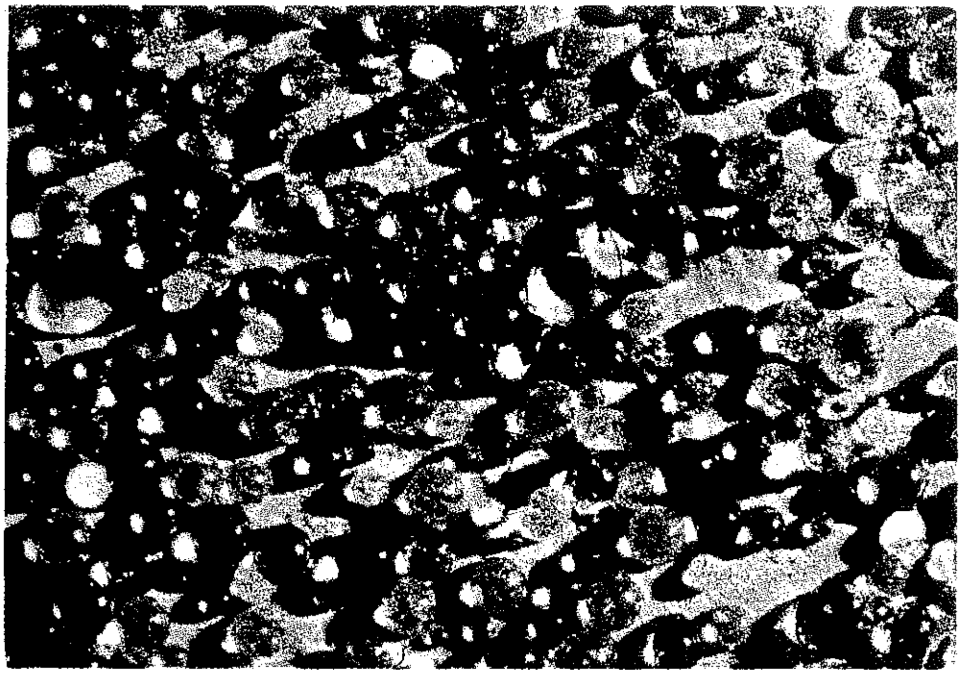
17 x magnification

Figure 17. Cataphote Floating Beads (Kentucky Gradation Specifications) Applied at 4.8 Pounds/Gallon (575 kg/m^3); Specimen of Line Preserved on Pick-up Panel; Summer 1974.



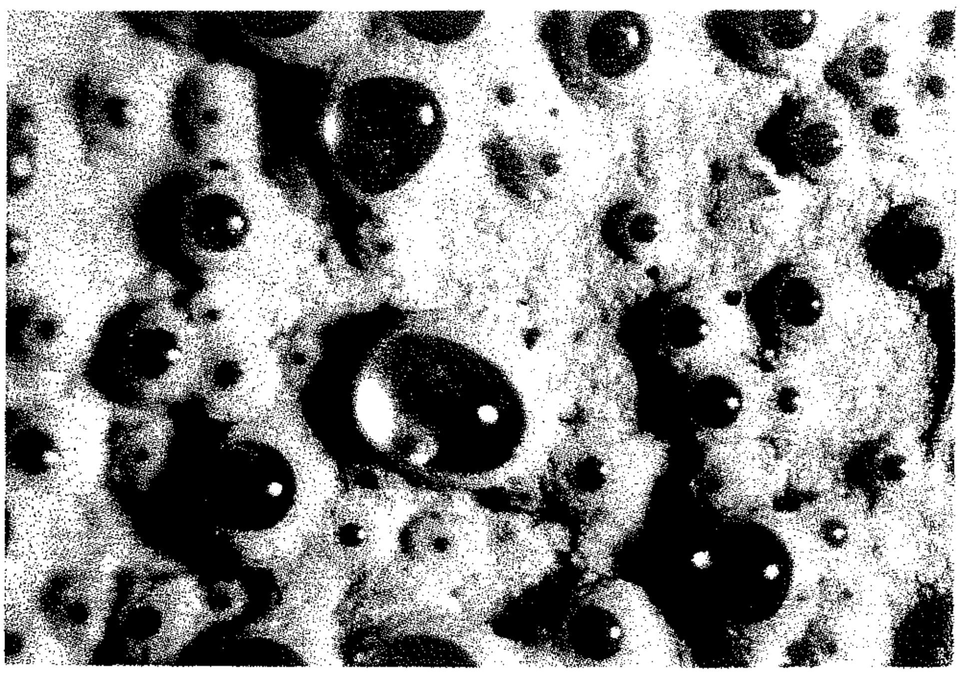
17 x magnification

Figure 18. Cataphote Floating Beads (Uniformly Graded) Applied at 5.8 Pounds/Gallon (695 kg/m^3); Specimen of Line Preserved on Pick-up Panel; Summer 1974.



17 x magnification

Figure 19. Flex-O-Lite Floating Beads Applied at 4.8 Pounds/Gallon (575 kg/m^3); Specimen of Line Preserved on Pick-up Panel; Summer 1974.



37 x magnification

Figure 20. Photograph of Good Bead Embedment from Reference 16; A. C. Peed, HRB Bulletin 57, 1952.

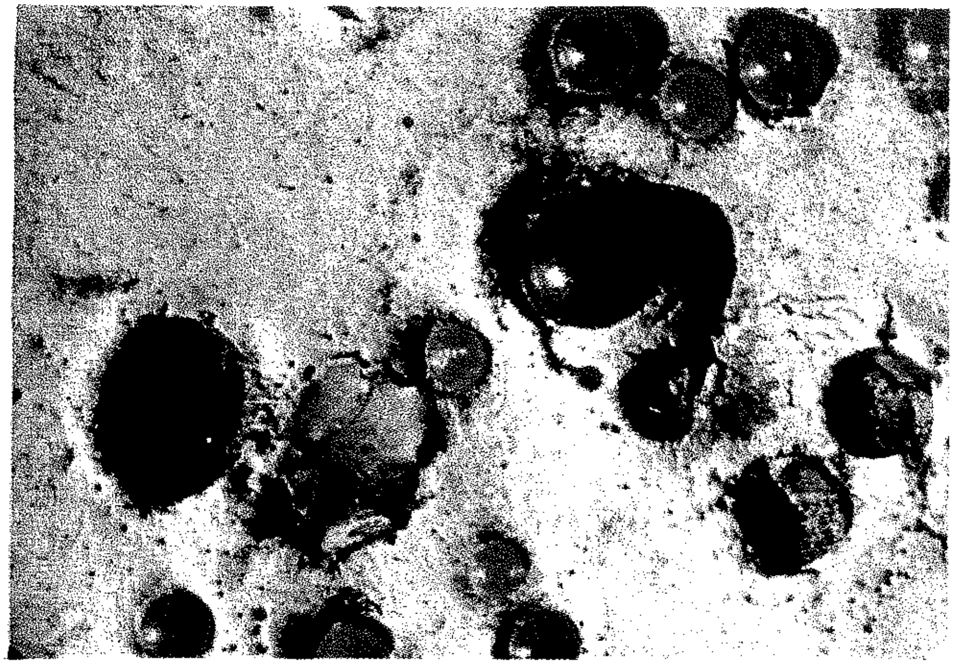


Figure 21. Cataphote TT-B Beads (1.92 Refractive Index) Applied at 5.0 Pounds/Gallon (599 kg/m^3); Applied in Summer of 1975, US 25 (Test Site); Photo Made in November 1975.

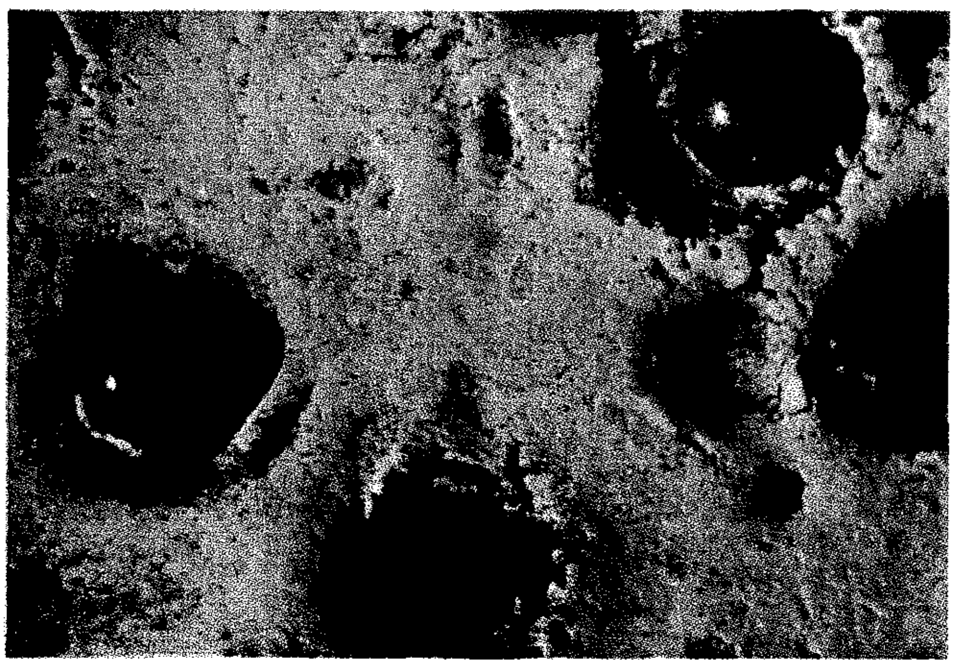
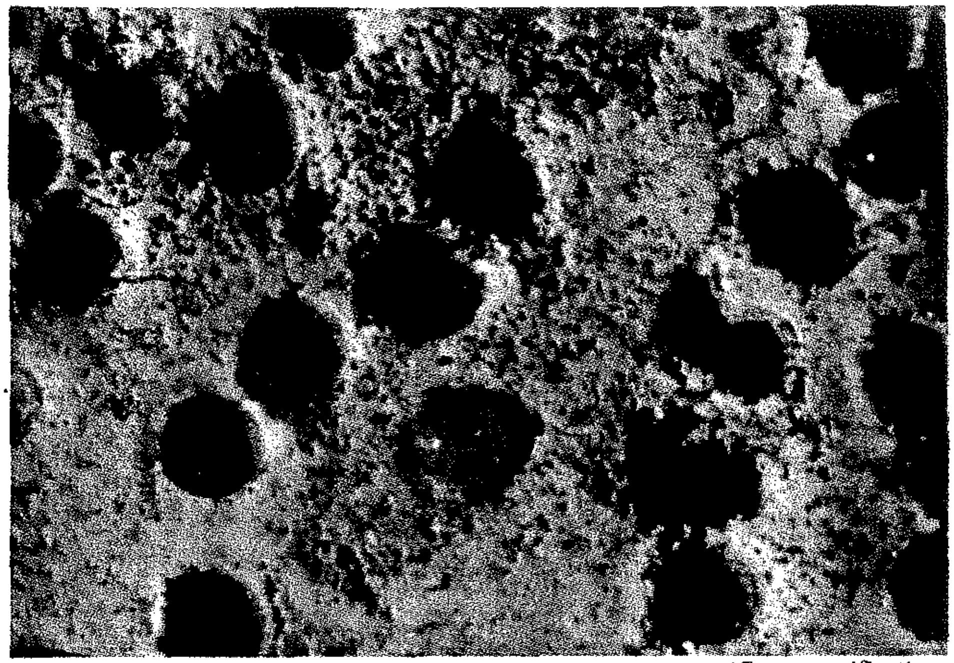
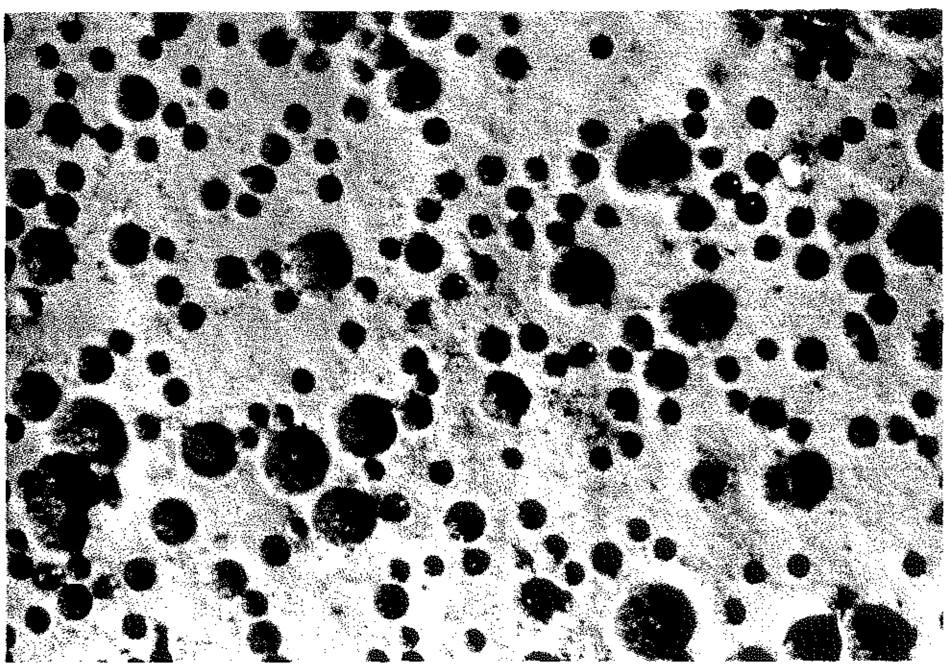


Figure 22. Cataphote Large Diameter Beads (-14 +18 Sieve Size and 1.65 Refractive Index) Applied at 4.6 Pounds/Gallon (551 kg/m^3); Applied in Summer of 1975, US 25 (Test Site); Photo Made in November 1975.



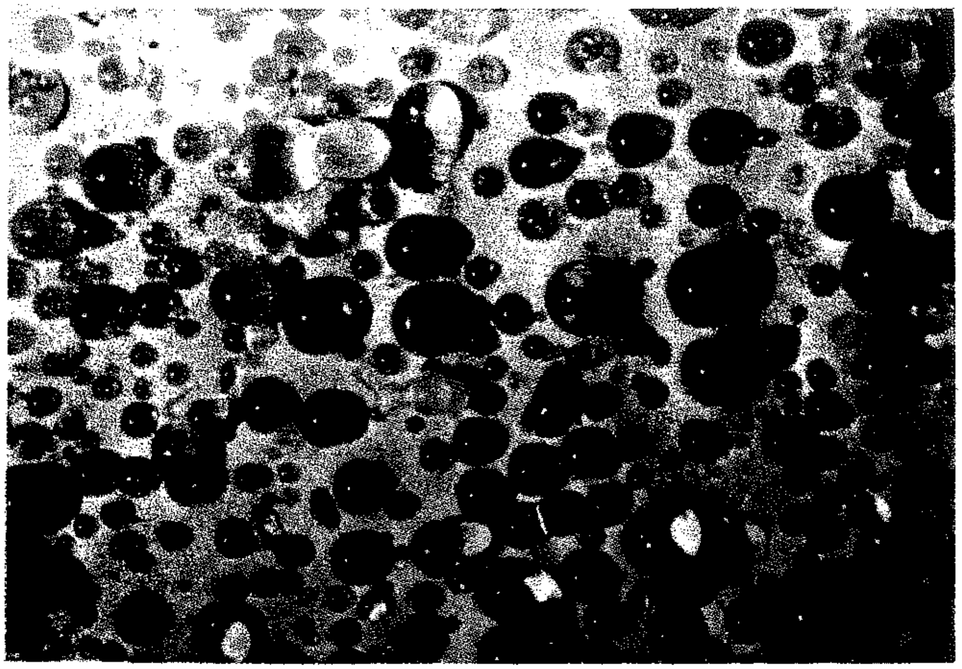
17 x magnification

Figure 23. Cataphote Large Diameter Beads (-20 +30 Sieve Size and 1.50 Refractive Index) Applied at 4.9 Pounds/Gallon (587 kg/m^3); Applied in Summer of 1975, US 25 (Test Site); Photo Made in November 1975.



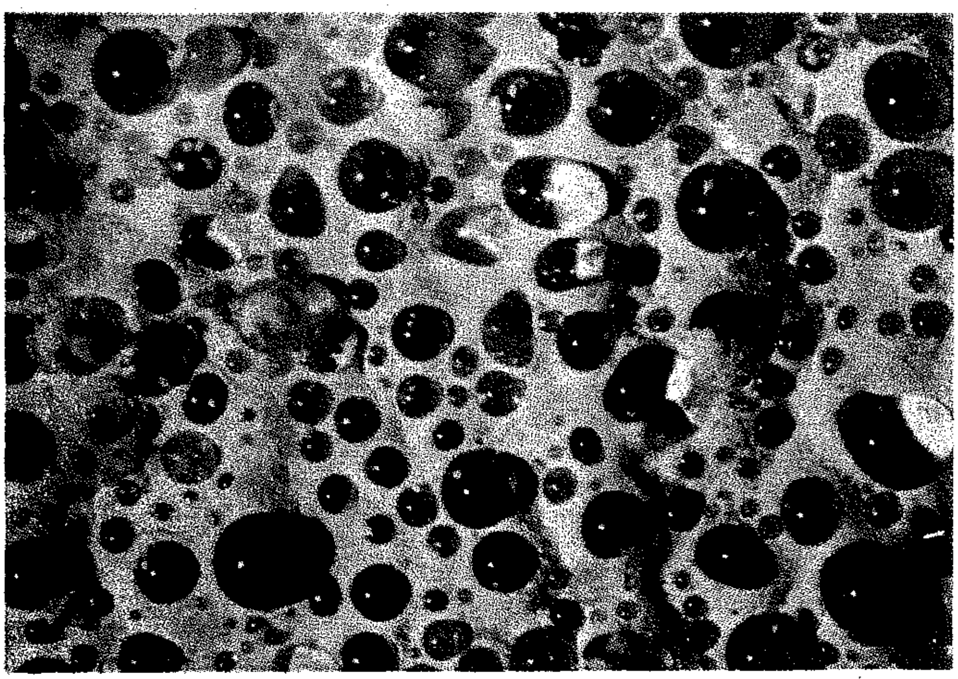
17 x magnification

Figure 24. Cataphote Hi-Glo Beads (1.65 Refractive Index) Applied at 4.7 Pounds/Gallon (563 kg/m^3); Applied in Summer of 1975, US 25 (Test Site); Photo Made in November 1975.



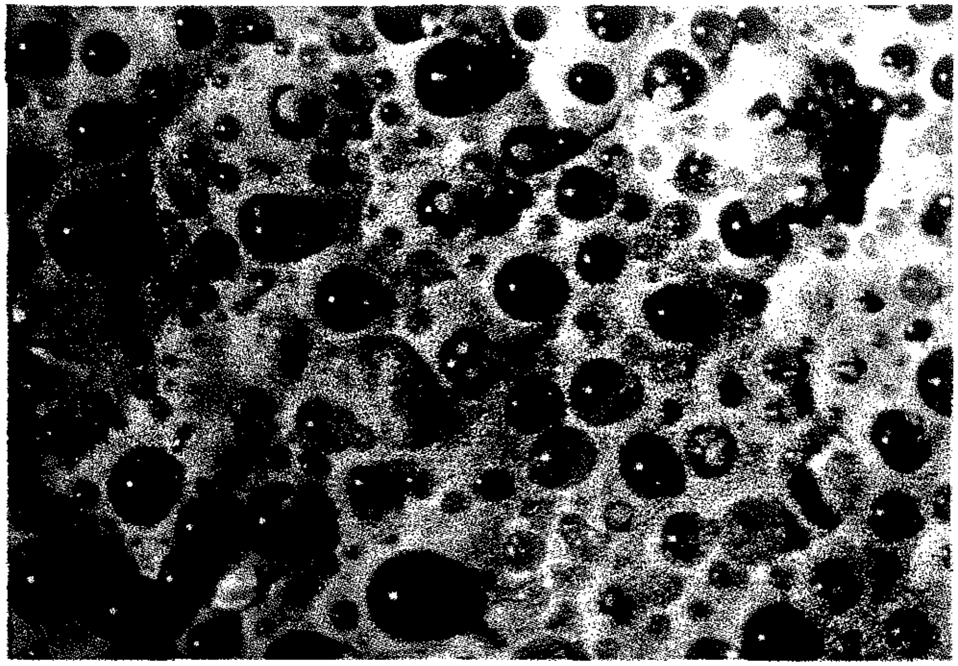
17 x magnification

Figure 25. Cataphote Regular Beads (Present Kentucky Specifications) Applied with Quick-Dry Paint Diluted Five percent with Solvent; Specimen of Line Taken on Pick-up Panel, November 1975.



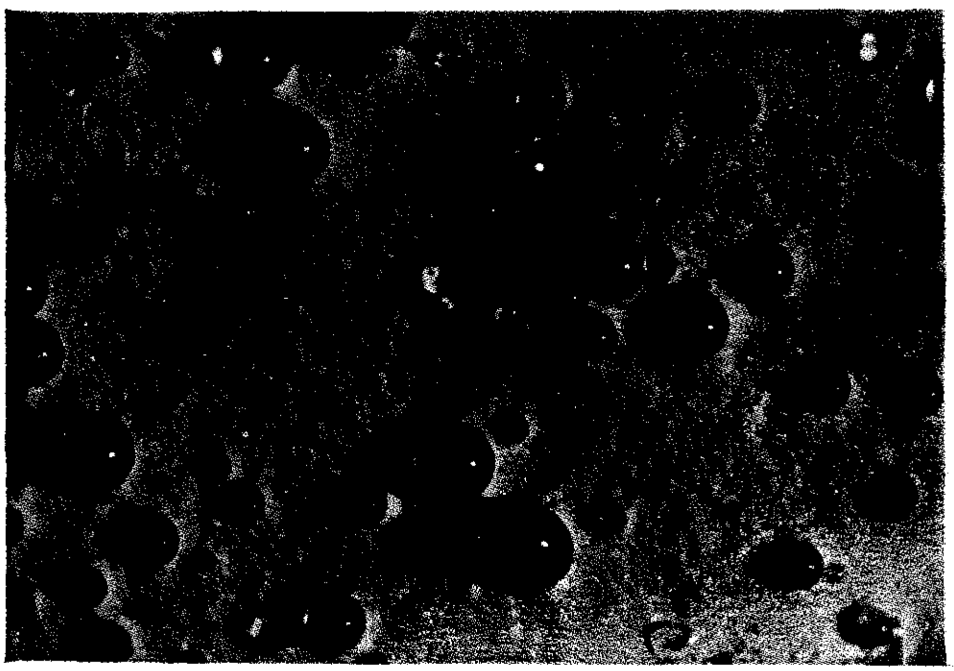
17 x magnification

Figure 26. Cataphote Regular Beads (Present Kentucky Specification) Applied with Quick-Dry Paint Diluted Ten Percent with Solvent; Specimen of Line Taken on Pick-up Panel, November 1975.



17 x magnification

Figure 27. Cataphote Regular Beads (Present Kentucky Specification) Applied with Quick-Dry Paint Diluted 15 Percent with Solvent; Specimen of Line Taken on Pick-up Panel, November 1975.



17 x magnification

Figure 28. Cataphote Regular Beads (Present Kentucky Specifications); Specimen of Line Taken on Pick-up Panel during Application by Paint-Striping Crew in District 7; November 1975.

17 x magnification

Figure 29. Cataphote Regular Beads (Present Kentucky Specifications); Specimen of Line Taken on Pick-up Panel after Adjustments Instructed by Traffic Division; District 5; November 1975.

Unless the beads are the floating types, there is a maximum limit on the application rate of paint to avoid inundation or drowning of beads of a given size and spacing. When graded beads are employed, some drowning of smaller beads is expected; however, they may become exposed later as the paint is worn off.

The optimum spacing of small, wetable beads for reflectivity during rain and wetness is estimated to be about 2.6 diameters, center to center -- that is, to minimize retention of water between beads (capillary-rise effect) and to maximize drainage. The minimum diameter of a bead, embedded midway in the paint, which will function optically during after-rain wetness is estimated to be about 15 mils (0.38 mm) (retained on a No. 40 sieve). The meniscus height on the bead was estimated from $h = 0.048 (1 - \sin \theta_w)$; also, $h = \sin \theta_c/2$, where d = diameter of beads; θ_w, the effective angle of wetting, was equated to θ_c, the critical graying angle of the light (assumed here to be 60 degrees) *(17)*. In a more general way, a projection or proudness of at least 1/8 inch (3.2 mm) above the surrounding plane is needed for a head to be reflective during a normal rain.

Economic Analysis

The well-graded, nonfloating bead presently used is applied at a rate of 6 pounds/gallon of paint (719 kg/m^3). As shown in Table 8, 2 million pounds (0.91 M kg) of beads are required annually at this rate of application. At 13 cents per pound (0.45 kg), this results in an annual cost of $260,000. The analyses given previously indicated that the application rate of the 1.65 refractive -index and the uniformly graded floating beads could be lowered to about 2.5 and 3 pounds of beads per gallon of paint (300 and 359 kg/m^3) without sacrificing luminosity. Using these bead types at an application rate of 4 pounds per gallon of paint (479 kg/m^3) would result in an annual savings of $60,000 for the uniformly graded floating bead and $33,000 for the 1.65 refractive-index bead. Also, results show that the application rate of the presently used bead could be lowered without losing much of the dry nighttime effectiveness and possibly improving wet nighttime effectiveness. An application rate of 4 pounds per gallon of paint (479 kg/m^3) could be used effectively. This application rate would result in an annual savings of approximately $87,000. No allowance for overspray or other losses is included in these estimates.

TABLE 8. COMPARISON OF COSTS OF USING VARIOUS BEAD TYPES AT CERTAIN APPLICATION RATES

BEAD TYPE	APPLICATION RATE IN POUNDS OF BEADS/GALLON OF PAINT (kg/m^3)	POUNDS OF BEADS REQUIRED FOR KENTUCKY (Mkg)	APPROXIMATE COST PER POUND (.45 kg) OF BEADS	TOTAL COST
Regular Nonfloating Well-Graded Bead	6 (719)	2,000,000 (.91)	$0.13	$260,000
Uniformly Graded Floating Bead	4 (479)	1,333,333 (.60)	$0.15	$200,000
1.65 Refractive Index Bead	4 (479)	1,333,333 (.60)	$0.17	$227,000

RECOMMENDATIONS

Based on the results of this study, the following recommendations are offered for implementation during the next paint-striping season:

1. The most apparent problem revealed during this study was poor embedment of beads. Evidently, the quick-drying paints dried too soon, and some increase in drying time may have to be accepted to obtain proper embedment. It is also recommended that a higher degree of quality control be observed by the supervisors of paint-striping crews to insure good bead embedment. (Examples of good embedment are presented in this report.)

2. Since none of the bead types were embedded properly during the evaluation, a recommendation of a specific bead is not possible at this time. However, rather than suggesting continued exclusive use of the present standard for beads, it is felt that results from the study warrant larger scale experimental evaluation of two other beads. These are a well-graded, 1.65 refractive-index glass bead and a uniformly-graded, floating, 1.52 refractive-index glass bead. It is recommended that 5,000 pounds (2,268 kg) of each experimental bead type be purchased for application in two of the 12 districts. Both beads should be applied at the rate of 4 pounds per gallon (479 kg/m^3).

3. In an attempt to solve the rainy, nighttime visibility problem, it is recommended that a large, 1.52 refractive index, nonfloating glass bead be applied at the rate of 4 pounds per gallon (479 kg/m^3) on all edgelines. Gradation specifications for this bead type are as follows:

SIEVE	PERCENT OF PASSING
No. 16	100
No. 30	15-35
No. 50	5-15
No. 100	0-5

4. All other applications of beads should be the standard glass bead (Special Provision No. 62-C) at the rate of 4 pounds per gallon (479 kg/m^3).

LIST OF REFERENCES

1. Pigman, J. G. and Agent, K. R., *Raised Pavement Markers as a Traffic Control Measure at Lane Drops,* Kentucky Bureau of Highways, Division of Research, Report 384, February 1974.
2. Pigman, J. G., Agent, K. R., and Rizenbergs, R. L., *Evaluation of Raised Pavement Markers,* Kentucky Bureau of Highways, Division of Research, Report 425, April 1975.
3. Anderson, D. R., Slater, D. E., and Cunningham, A. R., *Use of Rubber Snowplow Blades in Washington (Phase II),* Washington State Highway Commission, Department of Highways, September 1974.
4. Rahal, A. S. and Hughes, R. D., *Final Performance Report on Experimental Use of Thermoplastic Pavement-Striping Materials,* Kentucky Department of Highways, Division of Research, Report 290.
5. Seymour, W. M., *Grooving Pavement Centerlines for Lane Demarcation,* Kentucky Department of Highways, Division of Research, Report 314, October 1971.
6. Douglas, W. E., *Implementation Package for Use of Fast Dry Traffic Paint,* Florida Department of Transportation, January 1974.
7. Shuler, L. M., *Development of Optimum Specifications for Glass Beads in Pavement Marking,* NCHRP Final Report Draft, Transportation Research Board, May 1973.
8. Informational Literature from the Traffic Control Products Division of the 3M Company, St. Paul, Minnesota.
9. *Reflective Traffic Bead Study,* Department of Highways, Planning and Research Division, State of Colorado, Final Report, May 1970.
10. Croteau, J. R., *Evaluation of Floating Glass Beads for Traffic Stripes,* New Jersey Department of Transportation, Division of Research and Development, Research Report 72-002-7730, October 1971.
11. Sheppard, F. D., *Evaluation of Traffic Marking Beads and Paint,* Virginia Highway Research Council, December 1972.
12. Crumpton, C. F., and McCaskill, G. A., *Glass Beads in Paint,* State Highway Commission of Kansas, Planning and Development Department, Research Division, Report 2, 1970.
13. Chaiken, B., *Traffic Marking Materials -- Summary of Research and Development,* **Public Roads,** December 1969.
14. *Pavement Traffic Marking Materials and Application Affecting Serviceability* **NCHRP Synthesis Report No. 17,** Highway Research Board, 1973.
15. Chaiken, B., *Comparison of the Performance and Economy of Hot-Extruded Thermoplastic Highway Striping Materials and Conventional Paint Striping,* **Public Roads,** February 1969.
16. Peed, A. C., *Physical Properties of Traffic Paints,* **Bulletin 57,** Highway Research Board, 1952 (Kentucky Research Report No. 83).
17. Havens, J. H., and Peed, A. C., *Spherical Lens Optics Applied to Retrodirective Reflections,* **Bulletin 56,** Highway Research Board, 1952 (Kentucky Research Report No. 74).

APPENDIX

SPECIAL PROVISION FOR GLASS BEADS

KENTUCKY DEPARTMENT OF HIGHWAYS

SPECIAL PROVISION NO. 62-C
TYPE I GLASS BEADS

This Special Provision shall be applicable when so indicated on the plans, in the proposal, or in the bidding invitation.

I. DESCRIPTION

Glass beads, as covered herein, are intended to be used for reflectorizing centerlines, edge-lines, lane-lines, or other pavement markings by drop-on applications to any selected binder or adhesive and by such dispensing apparatus as may be devised or selected by the Department.

II. PACKAGING

The glass beads shall be packaged in one of the following: (1) heavy plastic-lined burlap bags, (2) multilayered moistureproof paper bags consisting of at least 2 layers of 40-pound natural kraft paper, 1 layer of 90-pound asphalt laminated paper, and 1 layer of 50-pound natural kraft paper; or (3) metal containers. The net weight of the package shall not be less than 50 pounds; and no overweight shall be credited or accrued.

III. SAMPLING AND TESTING

One package or container shall be selected randomly from each 10,000 pounds, or fraction thereof, comprising a shipment or consignment. A composite sample shall be prepared from all the selected packages or containers and tested as hereinafter specified.

IV. REQUIREMENTS

A. General. No extraneous materials or contaminants shall be present in the material, either as manufacturing aids or otherwise, which may adversely affect the adhesion of paint or the performance of the glass beads in providing the reflectivity required.

B. Physical Properties. When tested in accordance with the methods prescribed herein, the beads shall have the following properties.

1. Gradation. The size-gradation of the beads shall be determined in accordance with ASTM D 1214, and shall conform to the following requirements:

Sieve	Per Cent Passing
No. 16	100
No. 30	45-95
No. 50	15-35
No. 100	0-5

2. Imperfections. The total percentage of non-spherical, opaque, milky, scratched, and otherwise optically imperfect beads shall not exceed 30 per cent. The percentage of non-spherical beads shall be determined by ASTM D 1155, and the percentage of other imperfect beads shall be determined by microscopic count.

3. Refractive Index. The glass shall have a refractive index of not less than 1.50. The refractive index shall be determined by comparing the refractivity of the glass with standard refractive index liquids in accordance with recognized immersion methods (as applied to chemical microscopy and optical mineralogy).

4. Chemical Resistance. The glass shall withstand immersion in water and in acids without undergoing noticeable corrosion or etching and shall not be darkened or otherwise noticeably decomposed by sulfides. The tests for chemical resistance shall consist of one-hour immersions in water and in solutions of corrosive agents followed by microscopic inspection. A 3 to 5-gram portion of the sample shall be placed in each of three Pyrex-glass beakers or porcelain dishes; one portion shall be covered with distilled water; one portion shall be covered with a 3-N solution of sulfuric acid; and one portion shall be covered with a 50 per cent solution of sodium sulfide. After one hour, the glass beads in each portion shall be examined microscopically for evidence of darkening and frosting.

5. Moisture Resistance. The glass beads shall flow and cascade freely in the presence of humid air. These qualities shall be determined as follows:

Approximately 2 pounds of glass beads shall be placed in a clean cotton bag, untreated with sizing material, and of suitable capacity. The bag shall be immersed in water to a depth sufficient to cover the glass beads for at least 30 seconds and until fully soaked. The bag shall then be removed and wrung free of excess water and suspended in room air for two hours. The beads shall then be transferred slowly to a clean, dry, standard glass funnel having a 4-inch stem, and a 1/4-inch diameter exit. The entire sample shall flow freely through the funnel without stoppage. Light tapping to initiate the flow is permissible.

V. APPROVAL

No portion of a shipment or consignment shall be used before the beads have been tested as hereinbefore specified and approval is granted. Failure of any sample to meet any of these requirements shall constitute cause for rejection of the shipment.

APPROVED November 12, 1968

A. O. Neiser

A. O. NEISER
STATE HIGHWAY ENGINEER